Quality Uncertainty and Challenges to Wheat Procurement

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Issues related to quality uncertainty in wheat producing countries have escalated in importance in recent years. While Canada addresses these issues in part through variety regulations, firms in the United States resolve these through varying commercial strategies. Conventional alternatives for procurement range from spot purchases with specifications for easily measurable characteristics, to varying forms of strategies with precommitment. In grains, these are complicated by intrinsic uncertainty associated with functional qualities that are not easily measurable and that procurement costs vary spatially. Thus, shifting origins may involve higher cost due to having to bid grain away from its best market. We posed alternative procurement strategies and developed analytical models to evaluate the costs and risks of these in the case of hard red spring (HRS) wheat. Climatic conditions are a source of uncertainty in functional performance which reduces incentives for contracting and vertical integration, and poses a challenge to any form of integrated supply chain management.

Les problèmes liés à l'incertitude quant à la qualité des approvisionnements des pays producteurs de blé ont augmenté au cours des dernières années. Tandis que le Canada s'attaque à ces problèmes en imposant divers règlements, des entreprises états-uniennes les résolvent en adoptant diverses stratégies commerciales. Les moyens d'approvisionnement traditionnels varient des achats au comptant assortis de critères pour les caractéristiques facilement mesurables, à diverses stratégies comprenant un pré-engagement. Dans le secteur des céréales, la situation est compliquée par l'incertitude intrinsèque quant aux qualités fonctionnelles qui ne sont pas facilement mesurables et le fait que les coûts d'approvisionnements varient d'un endroit à l'autre. Par conséquent, s'approvisionner dans d'autres pays pourrait entraîner des coûts plus élevés en privant le secteur de son meilleur marché. Nous avons formulé d'autres stratégies d'approvisionnement et élaboré des modèles analytiques pour évaluer les coûts et les risques de ces stratégies dans le cas du blé de force roux de printemps. Les conditions climatiques sont une source d'incertitude de la qualité fonctionnelle qui diminue les incitatifs pour la conclusion de contrat et l'intégration verticale et qui pose un obstacle pour toute forme de gestion intégrée de la chaîne d'approvisionnement.

INTRODUCTION

There has been a resurgence of interest among agricultural economists and agribusinesses in recent years on alternative regimes for vertical management of the marketing system. In the case of grains attention is focusing on quality levels and consistency (Wilson and Dahl 1999) and variety identification in Canada (Oleson 2003; Furtan et al 2003). The spectrum of strategies for vertical control ranges from spot transactions to longer-term contracting

and ultimately complete integration. Many of these involve some form of supply chain management, which seeks to reduce costs by reducing sources of uncertainty. All of these have had a renewed emphasis on issues related to quality, consistency, and the efficacy of alternative procurement strategies.

The purpose of this paper is to analyze costs and risks associated with different procurement strategies. Alternative procurement strategies include what we refer to as naive, constant share, and opportunistic. The models use distributions for hard red spring (HRS) wheat and functional requirements for a specific product. Though the application is stylized for this particular industry, it could easily be applied to others. Of particular importance is the definition of the functional requirements, statistical distributions between measurable wheat and desired functional characteristics, and price distributions for different qualities and locations. There are three motivations for this paper. First, end-use firms need to evaluate among a set of alternative procurement strategies. Second, to some extent, public policy can facilitate among these choices. Finally, the analytical models provide a means to evaluate the risks and costs of alternatives. The paper contributes to the evolving literature on grain quality and explicitly analyzes the costs and risks of different strategies. Though applied here in the case of HRS, it could readily be applied to numerous other grains whose functional characteristics are random.

Quality consistency is a problem for buyers and has intensified competition among exporters (Wilson and Dahl 1999). In discussing these issues, a major importer noted "... inconsistency in quality of wheat from ship to ship—and even within a ship—proved to be a problem ..." (Sosland Publishing Co. 2001, p. 31). Ensuring consistency is problematic because end-use characteristics are not easily measured and therefore are not easily contracted. Hence, typically buyers use easily measured characteristics of grain as proxies for desirable end-use characteristics and/or varying forms of identify preservation (IP).

Canada has relied on variety regulations and class marketing, along with some sales sold through IP types of contracts using varieties and locations (e.g., Wharburtons (Kennett et al 1998) and malting barley in recent years). Visual distinguishability is a critical component of Canada's grain marketing system and has some appeal in part due to the costs of alternatives (Furtan et al 2003) relative to the prospective benefits (Oleson 2003). In an unregulated marketing system, procurement strategies vary widely from no precommitment and relying on easily measurable characteristics to more sophisticated strategies involving contracting and vertical integration (owning facilities in targeted regions).

Quality problems in grains are compounded by issues relating to attributes, the cost of information, moral hazard, and adverse selection. Since functional quality is random, obtaining information about performance is costly, requires expertise and *a priori* knowledge. Since the cost of information is nonzero there is a double moral hazard (Phlips 1988, pp. 57–60). The buyer is imperfectly informed about quality and the seller has imperfect information about buyers' use of the product. As a result, contracts and warranties are not easily adapted to resolve quality problems. Due to the randomness in functional performance, any warranty would be imperfect. Indeed, if the seller's description of the product "involves many attributes and/or much uncertainty about the final performance pattern over the sample of produced items, the warranty not only may require high enforcement costs, but may also become very complex to evaluate" (Tirole 1987, p. 107).

Marketing of CWRS in Canada differs sharply from marketing of HRS in the United States. In the case of HRS wheat, protein content, class and subclass are usually used as proxies for desirable functional characteristics. Most buyers specify these in their contracts, while others may specify varieties or functional requirements. Some firms have pursued vertical integration through asset ownership in targeted and diversified producing regions as an element of procurement strategy. For others, strategy is based on evaluation of wheat and flour characteristics based on samples collected through the harvest season. After testing, this information is used to target locations for procurement. However, use of preplanting contracts for particular quality characteristics is not common (MacDonald and Korb 2006). An important aspect of these procurement strategies relates to the inability to control quality due to exogenous effects (e.g., weather), which makes precommitment strategies less attractive.

QUALITY REQUIREMENTS, UNCERTAINTY, AND COST–RISK TRADE-OFFS

Procurement strategies for an end user were analyzed using a two-step process. First, procurement cost and the risk of not meeting quality requirements are quantified. The second defines optimal combinations of origins for targeting purchases. Models are developed to explore the extent that cost and risk can be reduced by targeting some combination of origins for procurement.

Elements of the Problem

There are 22 origins (O_j) defined as Crop Reporting Districts (CRDs) throughout the U.S. HRS wheat producing region. Prices at each are determined through intermarket competition representing movements to the east and west from the producing region. Futures are constant, but basis values at two geographically separated markets are random and correlated. The price at each origin j is derived as:

$$P_j = F + PP + \text{Max}\,[(B_{14,1} - S_{j,1}), (B_{14,2} - S_{,j,2})] \tag{1}$$

where F is futures and PP is the protein premium, each being a constant and independent of origin, $B_{14,1}$ is the basis for 14% protein, and $S_{j,1}$ is the rail shipping cost (for 26 car movements from) from origin j. Subscripts 1 and 2 refer to Minneapolis and Portland, respectively. This relationship allows for the origin price to be determined by the market that yields the greatest net return to the shipper.

Distributions for basis values were derived using data for the marketing years 1993/94–1997/98 and were taken from annual reports of the Minneapolis Grain Exchange (1993–1998) and the USDA Agricultural Marketing Service (1993–1998). Means and standard deviations with values in parentheses for market 1 and 2 were 80 cents/bu (45) and 125 cents/bu (46), respectively, and the basis values had a correlation of 0.92. For simulation purposes, the futures price (F) was 340 cents/bu.

Functional quality requirements are those representative of domestic or international end users using this type of wheat for a specific product. Requirements, denoted later by q_c, include wheat protein 14.2%; test weight 57 lbs/bu minimum, with discounts applied below 58 lbs/bu; absorption 63%; peak time 6.5 minutes; and mix

tolerance 12 minutes. All quality data were from public reports and/or original data collected for annual crop quality surveys from 1980 to 1996 (Moore et al various years).

Wheat quality characteristics include grade factors, test weight, and protein, are easily measured within the marketing system, and are used for contracting and transactions. Absorption, peak, and mix time are all critical functional characteristics. Since functional characteristics and wheat protein are correlated, it is common that protein is specified to achieve a targeted level of a functional characteristic. Statistical relationships are used to derive probability distributions for functional conformance.

Regressions using pooled data were estimated for each functional characteristic as: $U = \delta + \beta(M) + \gamma_1 O + \gamma_2 Y + \varepsilon$ where U is the value of the characteristic, M is the measurable wheat quality characteristic, in this case wheat protein, O_j $(O_1 - O_{22})$ and $Y(Y_{81} - Y_{96})$ are binary variables for origin and year, respectively, δ, β, and γ_1 and γ_2 are regression parameters, and ε is the error term. The data were pooled across origins and years. The results with respect to sign are as expected, notably a positive relation between protein and the functional characteristic. Further, there are differences across origins suggesting the importance of a target location strategy. The unexplained error from the statistical relationships (root means square errors (RMSE)) were retained and later utilized to represent uncertainty in the predicted values quality parameters in the simulation.

For the purposes of simulation, quality parameters for each location were treated as normal random variables with means equal to predicted values for each origin and quality factor and variability reflected by RMSE. The RMSEs were 0.96, 1.16, 13.85, and 17.18 for test weight, absorption, peak time, and mix tolerance, respectively. The RMSE indicates the risk confronting buyers. Larger values reflect greater inconsistency or variability that cannot be contracted using observable characteristics.

Uncertainty was incorporated by including randomness for test weight, functional characteristics (absorption, peak time, and mix tolerance), and in basis values at competing markets. Costs and risk of not meeting requirements were derived using stochastic simulation [@*Risk* (Palisade 1997)]. Risk is measured by the joint probability of meeting all wheat and functional quality requirements, which is the conditional probability given that the wheat purchase specification is 14.2% protein and test weight is at least 57 lbs/bu.

MODELS FOR ANALYZING PROCUREMENT STRATEGIES

Three procurement strategies are modeled and results compared in terms of cost and risk. These are referred as the naive, constant share, and opportunistic strategies. The objective functions are for an end user purchasing HRS wheat. The naive strategy is included as a base case for purposes of comparison and reflects the approach used by most domestic end users and importers. The other strategies seek to reduce risk through targeted procurement. The efficacy of these depends on costs and the correlations among quality deviations in each origin.

Wheat is produced and sold in regions with varying quality and price distributions as described in the preceding section. Let (p_j, q_j, r_j) represent realized price, actual functional quality, and measured wheat quality, respectively, in region j, and let $F_j(p, q, r)$ represent

the joint cumulative *ex ante* distribution of these variables in region j. The buyer is a price taker located east of market 1 and wishes to purchase a given volume of wheat which can be made from any of the regions $j \in \{1, \ldots, n\}$.

The "naive" strategy is to buy from the least cost origins each year, providing that specifications are met for the quality of the wheat using protein and test weight. Specifically, selecting all purchases from $j^* = \arg\min_j p_j$, is a cost minimization procurement strategy for a buyer who specifies only wheat characteristics. Functional quality is $E[q_j \mid j = j^*]$ and can be defined with information about each $F_j(\cdot)$. The problem in each year is to find j that minimizes:

$$\left[\underset{j}{\text{Min}} \left(P_j + S_{j,1} + S_{1,P} \right)^* W_j + \left(1 - W_j \right)^* \delta \right] \tag{2}$$

where P_j is the purchase price at origin j (defined above), $S_{j,1}$ is the cost of shipping from origin j to market 1, $S_{1,P}$ is the shipping cost spread from market 1 to the final destination, δ is a scalar representing price when specifications are not met, and W_j is a random variable which equals 1 if quality specifications for protein and test weight are met in region j and 0 otherwise.

An alternative would be to target specific origins over time, which are known to produce better quality, and to commit *ex ante* to purchase prespecified volumes from this region. This constant share strategy would target a portfolio of origins and identify shares from each that would result in a least cost combination for a given level of risk. This would generally be consistent with vertical integration or preharvest contracting on a routine basis (this would be similar to the Wharburtons contract).

One specification of the constant share model (Specification 1) seeks to meet requirements on average over time. This specification identifies the combination of origins, which minimizes cost while meeting requirements on average over time with probability $\geq \alpha$. Thus, some purchases within a year may not meet specifications and there may be years when the percent of purchases not meeting specifications exceed α; however, on average purchases will conform to specifications with a given probability. The problem is to choose values of $X_1, \ldots, X_n$ to minimize:

$$E\left[\sum_{j=1}^{n} \left(P_j + S_{j,1} + S_{1,P} \right)^* X_j \right] \tag{3}$$

Subject to:

$$Y_j = \prod_{i=1}^{m} Y_{ij} \tag{4}$$

$$E\left[\sum_j X_j Y_j \right] \geq \alpha \tag{5}$$

$$X_j \geq 0 \quad j = 1, \ldots, n \tag{6}$$

and

$$\sum_{j=1}^{n} X_j = 1 \tag{7}$$

where variables are as previously defined, E is the expectation operator, Y_{ij} is a random variable equal to 1 if quality specification i is met in region j and 0 otherwise, $Y_j = 1$ if all quality specifications are satisfied in region j, X_j is proportion of quantity derived from origin j, and α is a chosen probability level. Unlike the naive strategy this strategy involves an *ex ante* commitment to purchase from a subset of the regions.

Specification 2 differs slightly and requires identifying origins that result in the least cost combination for an acceptable level of risk. This is more restrictive because the percent of time that purchases from all origins have to meet specifications must exceed a prescribed probability. In contrast, Specification 1 only requires that through time, an average of purchases meet the specifications. Specification 2 identifies a combination of origins that minimizes cost for a specified level of acceptable risk—interpreted as the probability of meeting all requirements on all purchases over time ($=\alpha$). The problem is identical to that depicted above except that restriction 8 below replaces Equation (5) above:

$$\text{Prob}\left[\prod_{j:X_j>0} Y_j = 1\right] \geq \alpha \tag{8}$$

where α is the probability that all quality specifications for all purchases are satisfied in chosen regions.

There is an important interpretation of this model from a strategic perspective. Results prescribe regions in which all purchases would satisfy all specifications with a certain probability. For example, if $\alpha = 0.9$, then purchases from all of the targeted regions would meet specifications in 9 out of the 10 years. The difference between these two specifications is the second constraint (Equations (5) and (8)). In Specification 1, risk is defined as $E[\sum_j X_j Y_j] \geq \alpha$ meaning the probability of meeting specifications on average over time would have to exceed the critical value. In Specification 2, this is replaced by $\text{Prob}[\prod_{j:X_j>0} Y_j = 1] \geq \alpha$ meaning the joint probability of meeting quality requirements from all origins each year would exceed the critical value.

In the opportunistic strategy, wheat is purchased each year from the origin having the lowest cost and meeting functional quality requirements with a minimum acceptable probability ($=\alpha$). The origin of the shipments may change each year, in contrast to the constant share model, and shipments can shift among origins to seek out the lowest cost wheat that meets requirements. This strategy does not involve irrevocable commitments; the buyer has the ability to shift origins from year to year to take advantage of quality distributions and market conditions. Using this information, the buyer determines the relationship between measurable wheat characteristics and the distribution of quality. There is no commitment to buy from each origin every year.

Two important differences are incorporated in this model. First, instead of choosing fractions of shipments from each origin, a set of origins is chosen to target. The model was initially simulated using all origins and then reduced. This is relevant because in some cases it may not be cost-effective to execute this strategy using all origins—there may be fixed costs associated with quality evaluation and/or in monitoring supplier relationships across a large number of origins. Second, the procurement cost is as in the naive model. If specifications are met, the procurement cost and percent of time that origins are targeted are derived.

The problem is to choose a subset of regions R_k to minimize

$$E\left[\operatorname*{Min}_{j \in R_k}\left(P_j + S_{j,1} + S_{1,P}\right)^* Y_j + \left(1 - Y_j\right)^* 10\right] \tag{9}$$

Subject to:

$$Y_j = \prod_{i=1}^{m} Y_{ij} \tag{10}$$

and

$$\operatorname{Prob}\left[\sum_{j \in R_k}\left(Y_j\right) \geq 1\right] \geq \alpha \tag{11}$$

where k is the number of CRDs to target (the number of elements in subset R). Fractions that origins are utilized were calculated by evaluating which origin was least cost within each iteration, and splitting ties equality among low-cost regions meeting specifications.

Restrictions and Solution Techniques

The models were solved using simulation optimization models (Palisade 1998, p. 4), a hybrid of chance-constrained optimization and simulation models. The methodology utilizes simulation and allows for random variables. These were solved using *RiskOptimizer* (Palisade 1998), a program designed to solve optimization problems with uncertainty which uses a genetic search algorithm to identify optimal solutions. The model was simulated 1,000 times and the results used to derive the proportion of time each CRD (j) was utilized and the probability that functional characteristics (peak time, mix tolerance, and absorption) were met with this strategy.

Wheat and functional characteristics (test weight, absorption, peak time, and mix tolerance) and basis values at alternate markets were random variables. Two sets of correlations were imposed during the simulations. The first was among the error terms for the functional characteristic regressions in each region. This accounts for the fact that quality variables are correlated which affects any strategy involving targeting. The second was between basis values at competing markets. In addition, a restriction was imposed that total wheat purchases must not exceed 30% of production in the CRD.[1] It is unlikely that any single buyer could penetrate purchases of more than 30% of a CRD's production.

RESULTS

The naive strategy was simulated under two protein specifications. The base case requires 14.2% protein, or alternatively 15%. This strategy is used by most buyers without overt procurement strategies. Confronted with problems of functional quality risks and the inability to pursue more targeted location strategies, buyers normally specify higher protein levels to increase the likelihood of achieving desired functional levels, but at a greater cost.

With a protein specification of 14.2%, the average wheat cost is 444 cents/bu (Table 1) and a joint probability of meeting functional specifications of 0.61. Increasing the wheat protein specification to 15% increases the average cost to 462 cents/bu and the joint probability of meeting functional specifications to 0.76. Origins from which wheat would be procured are spread throughout the region, excluding Origins 5 through 8. The most any origin would supply would be 7%. There is a high risk that functional quality characteristics would not be met. Increasing protein levels to 15% increases the probability of meeting functional characteristics by 15%, but procurement costs increase by 18 cents/bu.

Table 1. Naive strategy results

Wheat protein specification	14.2%	15.0%
Probability of meeting specifications	0.61	0.76
Average procurement cost (cents/bu)	444	462
Targeted origins	Shares	
O_1	0.06	0.05
O_2	0.07	0.06
O_3	0.04	0.02
O_4	0.07	0.06
O_5	0.00	0.00
O_6	0.00	0.00
O_7	0.00	0.00
O_8	0.00	0.00
O_9	0.03	0.03
O_{10}	0.05	0.05
O_{11}	0.05	0.04
O_{12}	0.04	0.05
O_{13}	0.07	0.08
O_{14}	0.07	0.07
O_{15}	0.03	0.04
O_{16}	0.06	0.07
O_{17}	0.07	0.08
O_{18}	0.04	0.04
O_{19}	0.06	0.07
O_{20}	0.07	0.06
O_{21}	0.06	0.06
O_{22}	0.06	0.05

Table 2. Constant share strategy results

	Specification 1		
Probability of meeting specifications	0.8	0.85	0.9
Average procurement cost (cents/bu)	445	459	470
Targeted origins		Shares	
O_5		0.54	0.97
O_{17}	0.13	0.18	
O_{21}	0.87	0.28	0.03
	Specification 2		
Probability of meeting specifications	0.6	0.7	0.75–0.90
Average procurement cost (cents/bu)	445	451	471
Targeted origins		Shares	
O_5		0.20	1.00
O_{17}	0.79		
O_{19}	0.21	0.80	

The constant share strategy for Specification 1 was restricted to meet functional specifications 85% of the time (i.e., $\alpha \geq 0.85$). The average procurement cost is 459 cents/bu (Table 2) and purchases were concentrated among 3 origins with shares ranging from 0.18 to 0.54, and 82% of purchases coming from Origins 5 and 21. Increasing the probability of meeting specifications to 0.9 increased cost to 470 cents/bu, with 97% of purchases from Origin 5 and the remainder from Origin 21. Decreasing the probability of meeting specifications to 0.8, reduced procurement costs to 445 cents/bu, with 87% of purchases from Origin 21 and 13% from Origin 17.

Specification 2 was simulated at different probabilities of meeting specifications for all purchases each year (i.e., α was varied from 0.6 to 0.9). At a probability level of 0.9, all purchases would be targeted in Origin 5 and would have an average procurement cost of 471 cents/bu (Table 2 lower panel). This solution holds if the probability level is reduced to 0.75. At a probability level of 0.7, 20% of purchases would be targeted at Origin 5 and 80% from Origin 19, with the average procurement cost declining to 451 cents/bu. Reducing the probability level further to 0.6 reduces the average procurement cost to 446 cents/bu and targets procurement from Origins 17 (79%) and 19 (21%).

The opportunistic strategy was simulated at different probabilities of meeting requirements (i.e., α was varied from 0.90 to 0.99) with the maximum number of targeted origins equal to 5 (i.e., $N = 5$). At a probability level of $\alpha = 0.90$, the average procurement cost was 445 cents/bu (Table 3). Purchases over time would be spread among five origins in percentages ranging from 15% to 23%. Purchases would be targeted at these origins with purchases in any given year determined by lowest procurement cost

Table 3. Opportunistic strategy results

	0.90	0.95	0.99
Probability of meeting specifications	0.90	0.95	0.99
Average procurement cost (cents/bu)	444.5	444.5	444.6
Targeted origins		Shares	
O_2			0.15
O_5			0.02
O_{14}		0.15	
O_{16}	0.18	0.18	0.24
O_{17}	0.23	0.23	0.31
O_{19}	0.20	0.22	
O_{20}	0.18		
O_{21}	0.21	0.22	0.28

after postharvest evaluation of quality. Increasing (decreasing) probability of meeting requirements increases (decreases) average procurement costs minimally, but shifts the mix of origins.

In comparison, the naive strategy results in the least cost (by definition), but, involves a fairly high probability of not conforming to functional requirements. To overcome this, buyers could (and conventionally do), specify a higher level of quality than is actually needed, but in so doing incur a greater cost. The constant share strategy results in a higher probability of meeting requirements, but at a substantially higher cost. This would be reflective of strategies involving some form of precommitment contract or vertical integration.

The opportunistic strategy results in a lower cost and higher probability of meeting requirements than the other strategies. This strategy would involve making purchases each year from the origin having the lowest cost and meeting quality requirements with a minimum acceptable probability. In this strategy, shipments can shift among origins to seek out the lowest cost wheat that meets requirements. In contrast to the naive strategy, the expected cost would increase by an inconsequential amount, but the probability of conforming to requirements would increase from 0.61 to 0.99. In contrast to the constant share strategies, the expected cost would decrease from 470 (or 471 in Specification 2) to 445 cents/bu at a 0.90 probability of meeting functional requirements.

SUMMARY AND IMPLICATIONS

Grain procurement strategies are complicated by two factors. First, there is substantial variability in functional characteristics due to climatic conditions, but also variety choice and agronomic and marketing practices. Buyers typically make purchases based on more easily measurable wheat quality characteristics such as protein and absorb the risk of not conforming to functional requirements. Second, procurement costs vary spatially due to competing market regions. Thus, shifting origins usually involves a cost due to having to bid grain away from its best market.

We posed alternative procurement strategies and developed analytical models to evaluate their risks and costs. The results indicate that the naive strategy has the greatest

risk of not conforming to functional requirements. The opportunistic strategy, which allows purchases to shift among origins through time, has the lowest cost and highest probability of meeting functional requirements.

This paper was motivated to analyze the efficacy of procurement strategies in the case of grains. Although there has been an escalation of contracting in other agricultural commodities, this has been notably absent in the case of small grains. While there are likely numerous reasons for this, the results suggest that moral hazard would discourage use of contracting and warranty types of mechanisms for procurement. Indeed, strategies requiring precommitment, whether through contracting or vertical integration, are inferior to those that are more opportunistic. It is likely for these reasons that there has been minimal contracting and vertical integration in the case of small grains relative to other agricultural commodities. Similarly, many buyers' procurement strategies are evolving to choose target origins based on postharvest quality evaluation.

While these results do not use Canadian data nor the institutional details in Canadian grain marketing, some of the results are revealing. There is no doubt buyers are becoming more demanding and seeking more specific procurement solutions. The uncertainties analyzed here may be similar to those in Canada for a number of reasons, however, and the challenges are similar. Indeed some changes are emerging which can and do relate to these results. Certainly the Wharburtons example which defines locations, varieties and has some preshipment testing and quality evaluation, is beginning to look like what is suggested from our results. Also, the results conform to recent efforts on contracting malting barley (variety, location, etc.), which is under CWB control, as well as to oats. Looking forward, the Canadian marketing system will likely have to continue to evolve to allow and encourage more innovative strategies. Most important are issues related to targeting origins which generally are not facilitated in typical grain market transactions. Any supply chain strategy in grains must have the flexibility to shift origins as crop conditions change.

Several features of this analytical approach are particularly important and could be applicable in many other agricultural commodities. First, in many cases the functional performance in quality characteristics is random, and even if conditioned on easily measured proxies, there is a risk of not meeting quality requirements. Second, the cost–risk trade-off provides a primary motivation for the problem and reflects spatial differentials for costs and risks. Third, variability in functional characteristics may have correlations across origins that affect the efficacy of geographical diversification. The opportunistic strategy results are likely more appropriate for domestic end users, though more sophisticated importers working closely with suppliers could achieve some of these efficiencies. Finally, climatic conditions are a source of uncertainty in functional performance which reduces incentives for contracting and vertical integration, and poses a challenge to any form of integrated supply chain management.

NOTE

[1]A major end user suggested to us that it would not be possible to buy more than 30% of the wheat produced in a particular region due to competition from other buyers.

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